

BURNING FOR THE CONTROL OF APHIDS ON
ALFALFA IN THE ANTELOPE VALLEY OF CALIFORNIA

By R. A. BLANCHARD, associate entomologist, Division of Cereal and Forage Insects, Bureau of Entomology; H. B. WALKER, agricultural engineer, Agricultural Experiment Station, University of California; and O. K. HEDDEN, assistant agricultural engineer, Bureau of Agricultural Engineering, United States Department of Agriculture¹

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INTRODUCTION

The attacks of the pea aphid (*Illinoia pisi* Kalt.) on alfalfa have caused considerable loss of this crop in the Antelope Valley and in other districts in southern California since 1924. At times the cowpea aphid (*Aphis medicaginis* Koch) also becomes numerous on alfalfa in this district, but not so as to cause economic losses. The feeding of *I. pisi* upon alfalfa first checks the growth; and as the population increases and the feeding is prolonged, the plants in the more heavily infested areas become yellow, and finally the whole field may become brown and the plants desiccated. The only known remedy that can be applied to alfalfa fields so infested is to burn them over in the spring. To find an efficient method for accomplishing this, experimental work with the various types of burners was initiated by the United States Department of Agriculture.

In 1929 about 90 percent of the alfalfa fields in the Antelope Valley were severely damaged, and in 1930 and 1931 about 30 to 40

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percent. The damage occurs in the spring before the temperatures become high enough to cause rapid growth of the plants. Figure 1 shows a moderately large population of pea aphids on a large alfalfa plant. Much larger populations may occur even before plants reach the size of the one pictured.

Closely correlated with this damage is the problem of weed growth in the first cutting, which is made about the first of May. Aphid infestation has a direct bearing upon the weed problem, in that the aphids, by holding the alfalfa in check and causing more than normal thinning of the stands during the spring season, may thus allow the weeds to grow with less competition.



FIGURE 1.—Alfalfa plant bearing a moderate infestation of the pea aphid.

The length of time during which aphids are numerous enough to damage alfalfa has varied somewhat from year to year. During years having weather conditions approaching the normal for the valley the infestations were less widespread than in seasons having less than normal rainfall and a retarded spring. In normal seasons serious aphid populations have occurred from about March 1 to April 15. Cold winter weather usually retards damage until the middle of March, whereas a mild winter followed by a late spring tends to increase the severity and to prolong the period of damage. In 1929 severe infestations occurred from March 15 to the first

week in May, and some fields had not entirely recovered by the latter part of May. In 1930 and 1931 damage was evident the first week in March, and the fields had all recovered by April 30.

The rate and degree of natural recovery of alfalfa from aphid damage necessarily affects both the requirements for artificial control and the expense that would be justified in adopting control methods. Natural recovery has been observed to depend upon such factors as the occurrence of warm weather coupled with good moisture conditions resulting from either rain or irrigation. Not only are the plants able to grow more rapidly under such conditions, but high temperatures are distinctly unfavorable to this species of aphid and favorable to its enemies. The rapidity of recovery is influenced, even under favorable conditions, by the severity of the infestation and the vigor of the stand. Much thinning out of stands and a permanent weakening of the plants have been observed to

follow a severe infestation in fields known to be affected by bacterial wilt, even where such fields showed promise of good growth before the aphid infestation occurred. Early clipping of the damaged growth normally results in more rapid recovery.

FIELD BURNING FOR APHID AND WEED CONTROL

Burning over of alfalfa fields in winter or early spring has been an established farm practice in this section for some time. Usually this burning has been accomplished by simply setting fire to the dry plant growth along ditch banks and fence rows, or in the main part of the field. Such burning has been thorough only in those areas having an abundance of dry vegetative cover, and has accordingly been irregular in most fields. Some attempts at burning have been made by spraying fuel oil over the field and then igniting it.

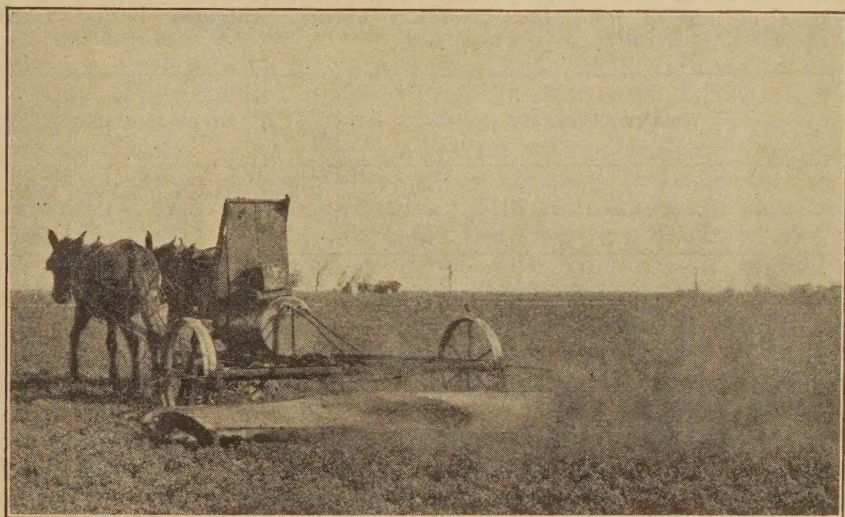


FIGURE 2.—The Canadian stubble burner.

The successful control of aphids and weeds in the Antelope Valley necessitates the burning over and destruction of all green growth in the alfalfa fields, and considerable interest has been shown by ranchers in this method. It was found that spraying oil upon the alfalfa and afterwards igniting it was not satisfactory. A number of field machines known as "stubble burners", manufactured in Canada, were in use in 1926 for burning aphid-infested fields. Other types of commercial field burners had been tried with varying success.

THE CANADIAN STUBBLE BURNER

The Canadian stubble burner (fig. 2) is a horse-drawn machine equipped with burners of the generative type which use a part of the heat to vaporize additional fuel as it is pumped under a hood. The fuel pump, which is the only part of the equipment requiring power, is driven through gears from the rear axle. The framework of the machine is constructed of metal, principally of angle or tubular cross section, except the hood supports, which are of flat bar steel,

and these seldom have sufficient strength and heat resistance to hold the hood in position. The hood covering is made of sheet iron. As this material oxidizes readily at high temperatures, this part of the equipment has a relatively short life in field service. Fuel from a 20-gallon tank located on the front of the machine is pumped to the heater coils at the rear at a pressure of 20 to 30 pounds per square inch. These machines are designed normally to burn a strip 12 feet wide. A perforated pipe inside a heavy steel-plate boxlike chamber makes up the heating unit which conditions the fuel for burning.

For satisfactory aphid control, fields are usually given two treatments with this machine, first being burned over entirely and then reburned. Table 1 gives the relative aphid control which was obtained with single and double burning when this type of machine was used.

TABLE 1.—*Relative effectiveness of single and double burning of alfalfa for the control of aphids with the Canadian burner, Antelope Valley, Calif., 1926-29*

Number of burnings	Fuel used per acre	Cost of fuel per acre	Cost of labor per acre	Degree of control
	<i>Gallons</i>	<i>Dollars</i>	<i>Dollars</i>	<i>Percent</i>
One.....	16	1.44	1.20	40-60
Two.....	32	2.88	2.40	84.6

Fuels ordinarily used in this type of burner are known locally as stove oil and distillate, having specific gravities ranging from 38° to 42° B. The use of fuels of lower grade results in burner decomposition and the rapid deposition of carbon on the inside of and in the orifices of the heater coils.

These machines have the advantage of low first cost, simplicity of construction, and reasonable safety in operation. The horse-drawn feature may be considered an advantage also where ranchers do not have tractors. Its disadvantages are inability successfully to use low-grade fuels, the necessity for double burning for effective insect control, rapid deterioration of the hood and heater coils under high temperatures, and low fuel capacity. The last-mentioned item causes considerable loss of time since the flame must be extinguished and the burners regenerated each time the tank is filled. Fuel is normally transferred from the supply tank to the machine tank by means of 5-gallon cans or pails. This is a slow and tedious operation. The fuel pump, being of a reciprocating type with single-acting cylinder and operating at relatively slow speeds, produces pulsations in the flame. Since this machine cannot be operated until a gas has been generated, the crop is likely to be damaged in spots from excessive heat exposure when burner generation takes place in the field. Carbon troubles are numerous, and uniformity of burning is difficult to obtain, particularly in windy weather.

EFFORTS AT CONTROL PREVIOUS TO THESE TESTS

Various cultural methods for control were studied, and it was found that winter cultivation and pasturing did much to discourage

infestations. Discontinuing irrigation early in the fall and allowing the alfalfa to mature as long as possible before the last cutting afforded some control. These were not direct, demonstrable methods of control, however, and objections were advanced to most of them by farmers. Early-spring irrigation followed by early cutting of the growth before it became severely damaged by aphids was successful, in most cases, when the spring weather was such as to allow the alfalfa to grow to a height that could be cut and raked. This method, however, did not control weeds to any appreciable extent, as they were largely grasses which would grow again in spite of having been cut.

Several different types of sprays had been tried, but none was successful. It was impossible with the spray methods available to kill the aphids located among the dense foliage. Granular cyanide scattered by a grain seeder killed the aphids on very young alfalfa but was not effective in older growth.

Stirniman and Ernst² conducted some field studies in 1926, in the Antelope Valley, with oil sprays on alfalfa fields followed later by burning. They found that 50 to 70 gallons per acre of fuel oil, when applied as a spray at a pressure of from 250 to 300 pounds per square inch, was fairly effective in fields having heavy stands with considerable dry stubble. Lighter oils, such as kerosene, lost considerably by evaporation, and greater quantities (75 to 100 gallons per acre) were needed for good results. In these tests burning followed the oil-spray applications, and was most effective when a light breeze was blowing. They reached the general conclusion that fuel costs should not exceed \$3.50 per acre. The fuels used, including the mixtures of kerosene, ranged from 14° to 27° B. gravity. They also made some preliminary tests with hooded burners of the generating type, but no conclusive data were obtained, although from 80 to 85 percent of the aphids were killed when the field was burned twice over at a speed of 2 miles per hour.

In 1926, and later, a number of burning machines with various arrangements thought to have value were constructed by ranchers and others. The burners were both of the generative and of the atomizing types. The majority of these machines were used only a short time and then abandoned, yet one or two have been used for a number of years and have given fairly satisfactory results. Several of the Canadian burners were still in use in 1929, and one locally-constructed machine of the same general type was also in operation. Prior to 1929, however, it had not been possible to carry on carefully controlled burning experiments in a manner calculated to give convincing field data. The effect of burning on weed growth was especially uncertain, as was the proper time when burning might be done most profitably. In some cases burned-over alfalfa was subsequently damaged severely by aphids, owing to the fact that it had been burned too early. More definite data were therefore necessary concerning the effects of burning upon aphids, weeds, and the alfalfa itself.

² STIRNIMAN, E. J., and ERNST, F. A. Reports on file at the University of California.

THE TESTS OF 1929 WITH A PUSHER-TYPE BURNER

In the spring of 1929 a burner which had been developed for burning corn stubble in the control work against the European corn borer at Toledo, Ohio, was brought into the Antelope Valley. This machine was built by the Division of Agricultural Engineering of the United States Bureau of Public Roads and was a mechanical atomizing pusher-type unit built around a tractor (fig. 3).

The burners, six in number, were fastened to a pivoted carriage attached to the front of the tractor and so constructed that a strip 7 feet wide could be covered as the burner moved forward. A single-acting, triplex, high-pressure pump, driven from the tractor by a power take-off, supplied fuel to the nozzles from the supply tank. The pump, fuel tank, and other equipment were mounted at the rear

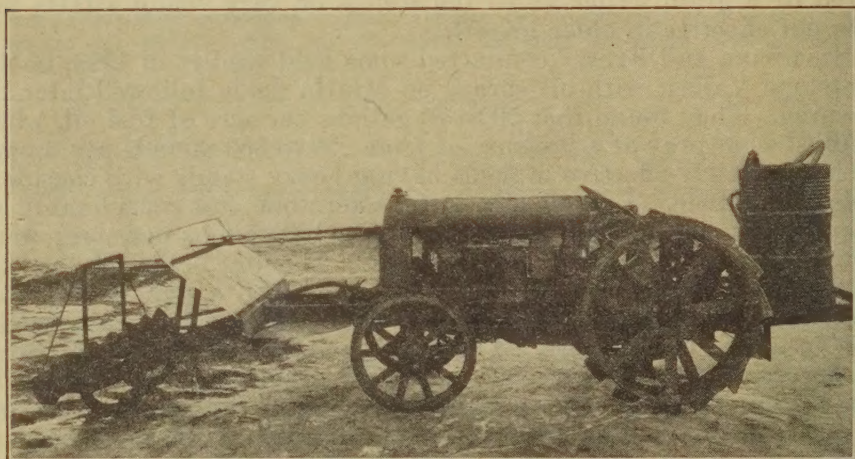


FIGURE 3.—Pusher-type burner used in the experiments of 1929.

of the tractor on a steel framework. The fuel was supplied to the spray nozzle at a pressure of 350 to 400 pounds per square inch. The nozzle (fig. 4) atomized the fuel through centrifugal force set up in the swirl chamber, by friction over the sharp edges of the small orifice, and by the subsequent flashing of fuel to vapor when suddenly released from high pressure. The brass nozzle caps, which are interchangeable, are made with different sizes of holes so that one may be selected which will deliver the proper quantity of fuel for satisfactory burning. In addition to the nozzle screen an auxiliary filter was used in the fuel feed line.

During the season of 1929 experiments were begun on March 5 and concluded on April 8. The control of aphids was unsatisfactory in the earlier tests because of inability to control and apply the flame properly. Data relating to the tests of 1929 are shown in table 2.

TABLE 2.—Data on burning with United States Department of Agriculture pusher-type burner for the control of the pea aphid on alfalfa, and Antelope Valley, Calif.

Date treated	Area covered per hour	Fuel used per acre	Control obtained	Nozzle orifice	Cost per acre ¹
1929	Acre	Gallons	Percent	Inch	Dollars
Mar. 5				0.028	
Mar. 6				.028	
Mar. 7	0.93	125.0	76-100	.028	11.25
Mar. 14			95	.024	
Mar. 15 ²		59.4	79	.024	5.35
Mar. 18		43.0	100	.024	3.87
Mar. 18, 19 ²			99	.024	
Mar. 26		54.3	99	.024	4.89
Apr. 8		50.8	95-99	.024	4.57

¹ Figured at 9 cents per gallon for fuel used.² Double burning.

Mechanical problems hampered the work considerably in 1929. The rigid character of the framework made it impossible to hold the flame close to the ground, particularly when crossing irrigation borders. The inefficient application of the heat caused excessive fuel losses, resulting in high costs per acre. The first cost of this machine, based upon 1929 prices, was approximately \$800, exclusive of the tractor. The best results were obtained from the higher grades of fuel, such as stove oil having a Baumé gravity of 38° to 40°.

It was apparent from these experiments that some method for better control of the flame was necessary. The strong winds, common to the Antelope Valley, sometimes blew out the flame, and when it was burning the flame was whipped about so violently that it could not be applied where most desired. Furthermore, these conditions were hazardous to the operator as well as to the equipment. Experiments with hoods and shields constructed of common galvanized sheet iron improved the operation of the burners, but the results were generally unsatisfactory because of rapid oxidation of the metal when subjected to high temperatures. In addition to the trouble from wind-blown flame the pusher type of machine had the added disadvantage that the tractor and operator passed over the burning material and, if much dry debris were present, the fire and smoke made operation both unpleasant and dangerous. In some of the tests the tractor was run backward over the plots to be burned.

The field work of 1929, however, disclosed several leads to be followed in the design of burning equipment for aphid control, the most important of which was the need of housing about the burners for flame and heat control. Other points of importance were the need for greater flexibility of frame, ability to utilize lower grades of fuel, simplicity of construction, ease and safety of operation, and the need for nonoxidizing materials for the hood parts subjected to high operating temperatures. The tests in 1929 indicated that aphids could be controlled by burning, and that the treatment should be relatively late in the season. Burning produced a noticeably beneficial effect on weed control and plant development.

THE EXPERIMENTS OF 1930

The equipment used for the experiments of 1930 differed from that used in 1929 in three fundamental respects: (1) The burner unit, which was built separate from the tractor, was drawn instead of pushed; (2) a flexible hood constructed of heat-resisting metal was used to form a combustion chamber; and (3) an auxiliary air supply was provided to promote rapid and more complete combustion of the fuel. All of these features were incorporated into a single drawbar machine which is shown diagrammatically in figure 5, A. Figure 6 shows a view of the machine in actual field operation.

The framework of the machine was of light structural steel with sufficient over-all width to permit burning a strip 7 feet wide. The

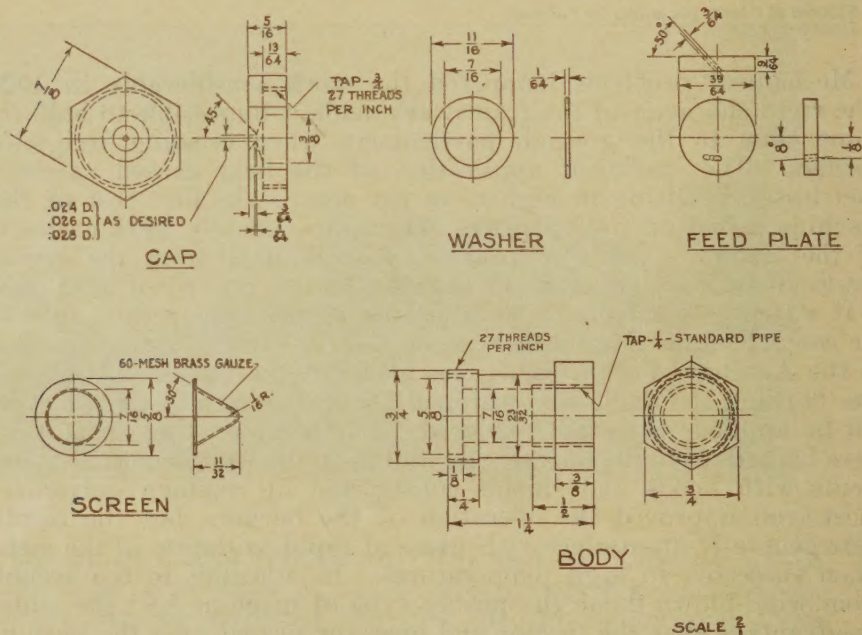


FIGURE 4.—Details of the Worthley nozzle.

hood, forming the combustion chamber, was 12 feet long and built of a chromium-iron alloy which would not oxidize at high temperatures. To provide for the expansion and contraction of the metal and to keep at a minimum the flame and air leakage from the hood with a minimum of dead weight, the hood was built up with 20-gage metal sheets 14 inches square. These sheets, overlapping one another, were supported at intervals of 6 inches in two directions from overhead supports so that the entire hood, although flexible, was held to shape. The fuel pump and fan were operated through a power take-off from the tractor. The fuel pump and atomizing equipment were similar to those used on the 1929 machine except that a multi-blade fan was used to supply air for combustion. This fan had a manufacturer's rating of 2,010 cubic feet of free air per minute against a static pressure of 2 inches of water, when operating at 1,363 revolutions per minute. The fan was equipped with regulating

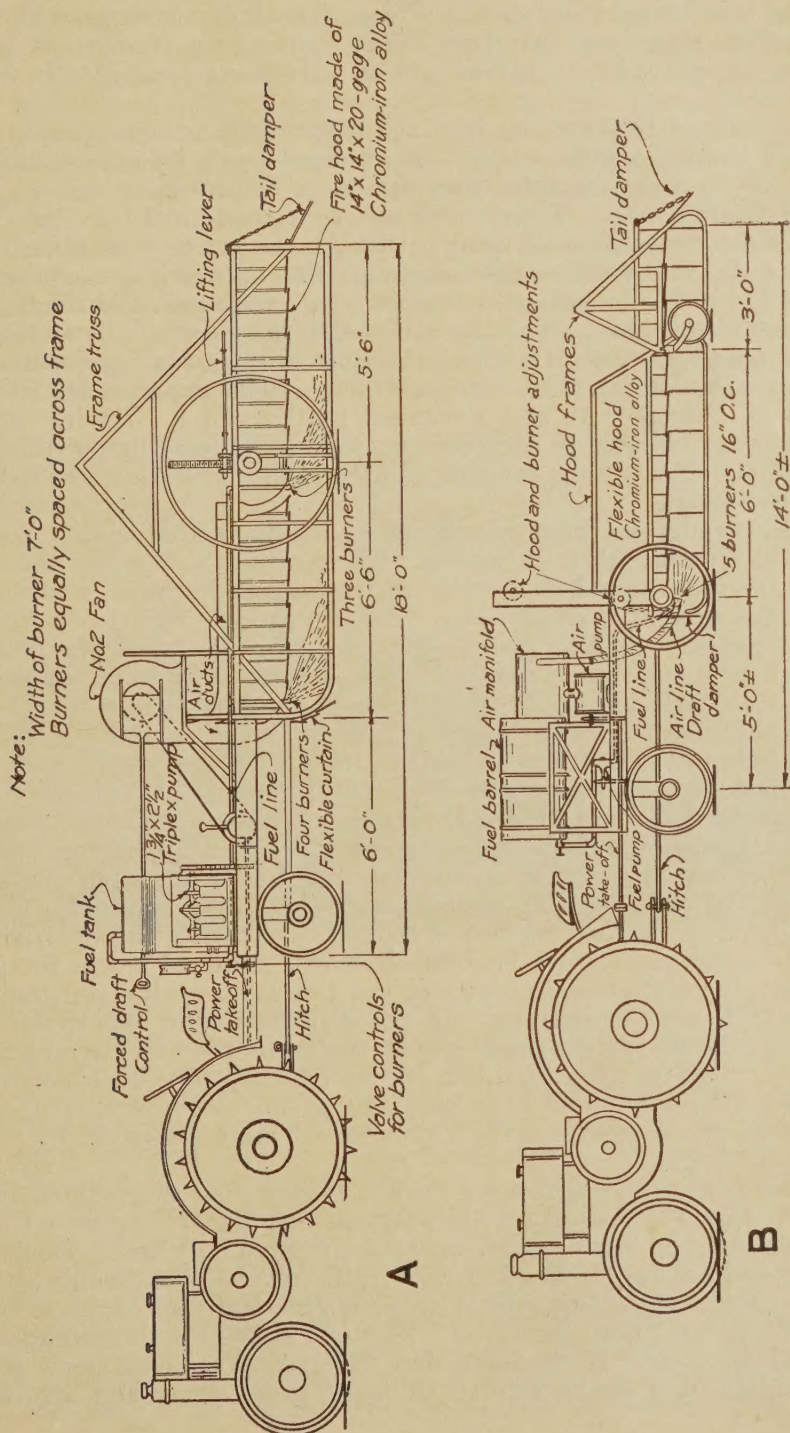


FIGURE 5.—General construction of the burners designed by the United States Department of Agriculture for use in aphid and weed control:
A, The 1930 burner; B, the improved type used in the experiments of 1931.

valves or gates on the intake side so that the proper quantity of air for efficient combustion could be supplied to the nozzles at all times. The fuel was drawn from standard 50-gallon oil drums supported on the machine frame and delivered to the nozzles at a pressure of 350 pounds per square inch. Quick shut-off valves were provided in the fuel lines.

The spring of 1929 was one in which widespread damage by aphids occurred throughout the valley. High winds were of almost daily occurrence, and the mean temperatures were considerably below the normal for this area. These conditions continued until very late in the season. Seasonal conditions in 1930, however, were much more favorable for an experimental program. Strong winds occurred occasionally but did not seriously interfere with the work, and the temperatures were higher. The damage to alfalfa by the aphids was not so widespread, nor was it prolonged so late in the spring, yet abundant opportunities for tests were provided. Field experiments were started on February 18 and continued until April 5. During this period it was possible to carry out varied experiments under different field conditions, thus securing a more comprehensive set of data than previously.

Aphid populations were determined by making actual counts from five-plant samples taken at random. These counts were made before burning and at intervals following treatment, both in the area burned and in the untreated check plats. Alfalfa growth was determined also by measuring plant growth at different locations in the field. All fuel consumed was weighed and the corresponding burned area measured, so that costs and rate of burning could be computed.

Difficulties experienced in burning fields in which the alfalfa growth was tall and green, or which contained green weeds, caused experiments with clipping and double burning to be tried. In the clipping experiments ordinary horse-drawn mowers were used; and the cut stems, if too short to be recovered for hay by raking, were allowed to dry undisturbed in the field. These stems often settled into the alfalfa crowns in a somewhat compact layer, especially if a period of rainy weather intervened between the cutting and the burning. In order to promote combustion of this material it was found advisable, in most cases, to loosen or stir this layer with a peg-tooth harrow just prior to burning. In the double-burning experiments, time was allowed for the plant growth seared by the first burning to become dry before the second burning was attempted. This usually was from 1 to 3 days. If the intervening time were much longer, the alfalfa plants sent out new shoots, which were destroyed by the second burning.

Double burning checked weed growth longer than single burning, but such weeds as foxtail and brome grass ultimately reappeared in the double-burned areas as well as in those treated only once. Double burning did not appear to affect the alfalfa adversely, although with the mechanical atomizing type of machine practically all of the stems above the ground were destroyed. Figure 7 shows the thoroughness of double burning. In the immediate foreground the long stems are the remains of a heavy growth of large green grass and alfalfa crowns.

EXPERIMENTS IN 1931 WITH AN IMPROVED BURNER

Experiments in 1931 were made with an improved field burner of the air-atomizing type (fig. 5, B), designed and constructed by the United States Department of Agriculture. The change in type of burner was thought desirable, (1) to eliminate the high fuel pressure required in the mechanical atomizing type, (2) to provide greater safety for the operator, and (3) to obtain greater economy of operation. Figure 8 shows a view of this machine, which in general appearance is similar to the one used in 1930. As this machine embodies the improvements that were devised after considerable experimental work, a detailed description of it has been prepared and will be presented under a separate heading. (See p. 18.)

General conditions in 1931 as to aphid populations and weather were somewhat similar to those of 1930. However, no precipitation occurred between February 19 and April 25 which made moisture



FIGURE 6.—The 1930 burner in use.

conditions distinctly less favorable for plant growth than those of the preceding season. Field work with burning equipment began February 24 and was concluded April 6. Methods of obtaining records of population and costs of treatment were similar to those of the previous year. Data regarding growth were taken in a slightly different manner. Each green shoot from the sample taken for population records was counted and measured. Average lengths were then determined by dividing the total culm length by the number of shoots found in the 5-plant sample.

The preparatory treatments studied during the season of 1931 consisted in preliminary burning and clipping. Attention was given to irrigation following burning to determine whether timely application of water would assist the early burned plots in resisting reinfestation. It was found that irrigation was desirable as soon as the alfalfa had begun to renew its growth, usually from 4 to 6 days after burning.



FIGURE 7.—A double-burned field showing thoroughness of the burning.

Results for the years 1930 and 1931, when aphid populations were closely observed, show that it is possible to control infestations by burning; although, under many conditions, the economy of such control may be questionable. Figures 9, 10, and 11 show the seasonal records of typical treated and untreated plats for different burning dates. It will be noted that early burning permitted heavy reinfestation to occur. It therefore appears obvious that control should



FIGURE 8.—The 1931 burner in operation.

not be attempted too early in the season. The graphs of later-burned areas show either the aphids failing to multiply on the new growth or a late infestation of no great magnitude, and a dying out before serious damage resulted. In nearly every case, greater growth was noticeable on the late-burned fields.

Plats in a very weedy field burned March 10, 1930, showed a reduction of nearly 50 percent in the number of weeds as well as considerable reduction in the size of heads and number of weed seeds in the first crop of hay. Plats burned before that time did not show

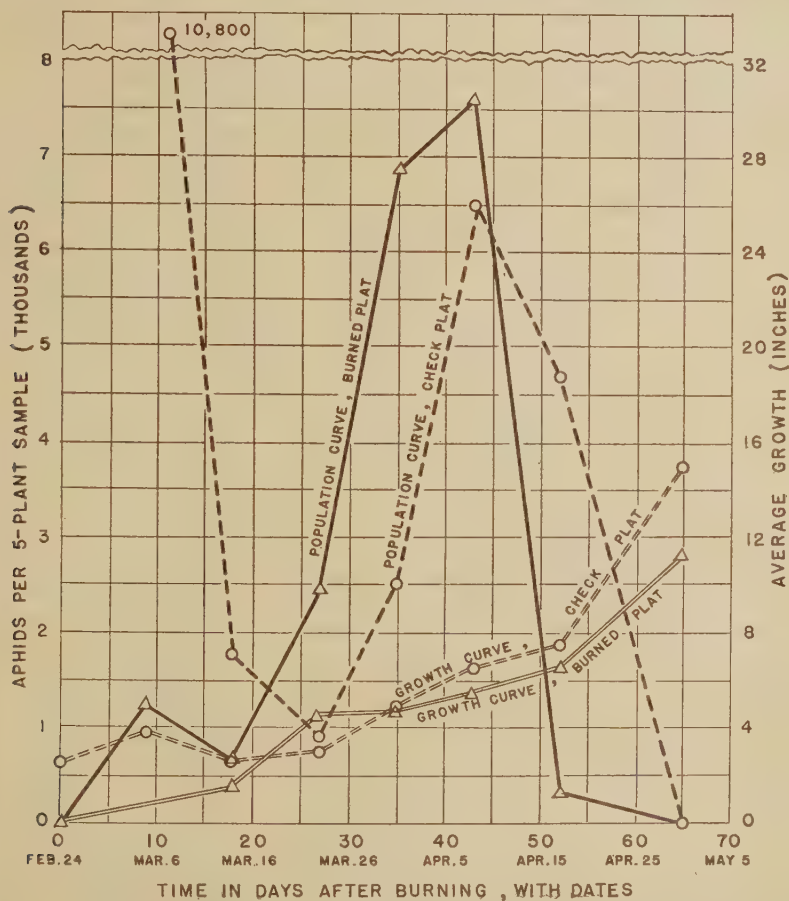


FIGURE 9.—Aphid population and alfalfa growth in plats burned early in the season in comparison with unburned check plats, 1931.

any noticeable weed control, whereas plats burned from March 28 to April 6 had almost no weeds in the first crop. Similar results were obtained in 1931. Burning weed growth in alfalfa when the weeds had attained seed heads resulted in a clean first cutting of alfalfa for the year in which the burning was done. Weeds reappeared in such fields the following year, owing, no doubt, to the fact that the seeds of such plants (principally foxtail and brome grass) do not all germinate in any one season. Burning, therefore, must necessarily be done every year for weed control and the cost charged against the value of the first crop.

NATURAL FACTORS AFFECTING EFFICIENCY OF BURNING

Natural factors which influence the effectiveness of burning were (1) age and growth of alfalfa plants, (2) dew, (3) degree of aphid damage, (4) weed growth, (5) wind, and (6) temperature and humidity.

Old stands of alfalfa are more difficult to burn effectively than new stands because the crowns are denser, and it is not so easy for heat to penetrate to the bases of plants in thick stands as it is in thin stands of the same age.

Moisture from dew or rain greatly reduces the effectiveness of burning because of the large quantity of heat used in evaporating the thin film of water on the plants and on the ground.

Tall growth that is not seriously dried out by the feeding of aphids is very hard to burn, and if there is necessity for burning such a field

for either aphid or weed control the growth should first be cut and allowed to dry thoroughly before being burned. Fields badly damaged by aphids often contain a large quantity of dry plant material. This burns readily with an effect similar to that of dry weeds, straw, or clipped material.

Weed growth may either aid or hinder burning. If weeds have made some growth in the fall and the leaves and stems have dried during the winter, this material supplies dry

cover, which aids considerably in building up lethal temperatures in the alfalfa crowns. On the other hand, a damp, green growth readily uses up heat, thus making lethal temperatures difficult to attain.

Wind velocities ranging from 2 to 25 miles per hour were experienced during the experiments, and were observed to affect burning in several ways. Periods of relative calm somewhat reduced the efficiency of the burner, the flames being smothered by lack of air after the burner had passed over a given area. Winds above 12 or 15 miles per hour reduced the effectiveness of after-burning by blowing the flames out in all but the most protected places. Wind velocities of from 5 to 10 miles per hour furnish the most favorable conditions for complete burning of the plant material in that an abundance of air is supplied, but the flames are not extinguished by the breeze. The best aphid control was secured under such conditions.

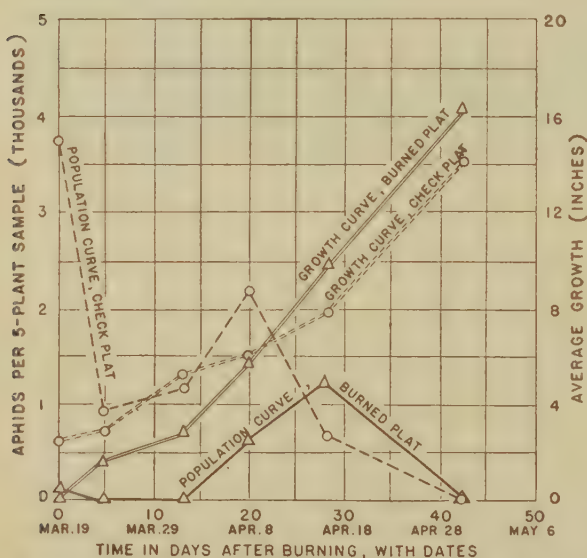


FIGURE 10.—Aphid population and alfalfa growth in plots burned near the optimum date in comparison with unburned check plots, 1930.

Burning should not be attempted when the wind movement is greater than 25 miles per hour.

Temperature and relative humidity had a direct effect upon burning, as might be expected. The high relative humidity of a cloudy day made the dry trash or plant growth in an alfalfa field less combustible. On the other hand, high temperatures caused the aphids to ascend the plants or to migrate on the surface of the soil in the open rather than to collect at the bases of the plants for protection, as they were likely to do on cool days. These factors influence the correct operating height for the hood. During both seasons (1930 and 1931) the height of the hood from the soil surface was approximately 12 inches. This was found to provide sufficient combustion space so that a clean flame, free from black smoke, could be produced under most conditions.

RELATION OF BURNING TO APHID MORTALITY AND REINFESTATION

With the machines used in the experiments of 1930 and 1931 excellent results were obtained in every case where soil and crop conditions were right for burning. The destruction of aphids resulted from direct killing by the heat and indirect killing by starvation and desiccation due to the destruction of the alfalfa tops. The direct kill ranged from 91.9 to 99.9 percent, based upon plant counts in the same areas before and after burning. Owing to the high reproductive rate of the pea aphid, no long time is required, under favorable conditions, for treated alfalfa fields to become critically reinfested. Succulent, fast-growing alfalfa in burned-over fields provides these favorable conditions. For this reason the optimum time for burning is restricted. March 12 was the earliest date on which burning resulted in a smaller maximum population than on the unburned plats. Reinfestation is due to several factors:

- (1) The greater succulence of the alfalfa growing on areas that have

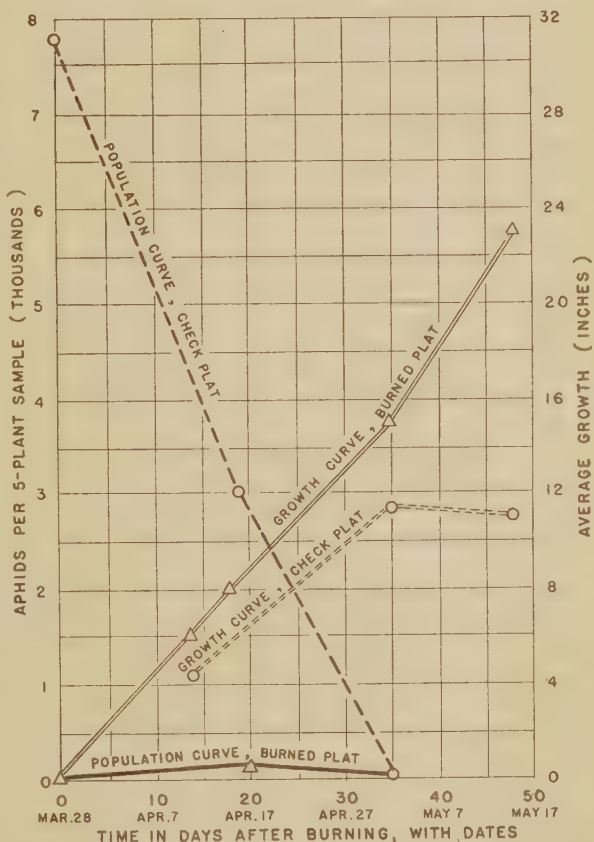


FIGURE 11.—Aphid population and alfalfa growth in late-burned plats in comparison with unburned check plats, 1930.

been burned over allows more rapid reproduction by those aphids not destroyed, and its green growth protects them from the sun and wind and furnishes a greater food supply; (2) incoming winged migrants add to the population; and (3) a large percentage of the natural enemies of the aphids are destroyed by burning, especially where burning is done early in the season.

After March 12, however, the period between the time of burning and the time of unfavorable natural conditions was too short for a large population to build up. Figure 12 indicates the relationship

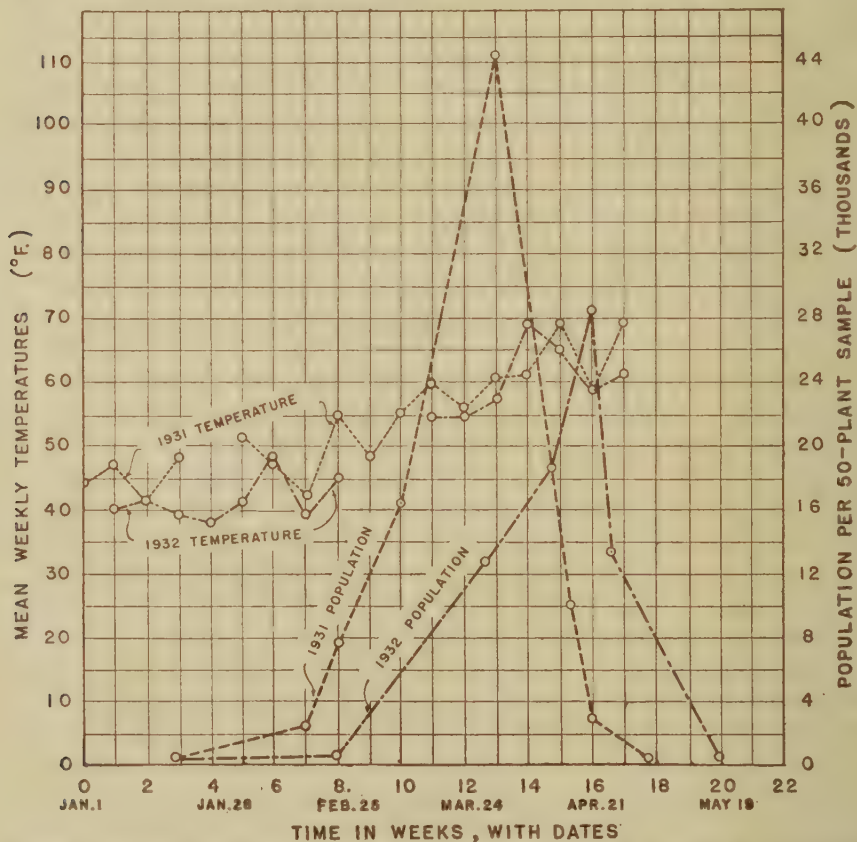


FIGURE 12.—Weekly mean temperatures and aphid populations in 10 fields in the Antelope Valley, Calif., 1931 and 1932.

between aphid populations and temperatures for the years 1931 and 1932.

EFFECT OF BURNING UPON PREDATORS AND OTHER INSECTS

The effects of burning upon predators and other insects associated with the aphids varied with the developmental stage of the insects, the time and thoroughness of the burning, and other factors. In nearly all of the experiments the growth was desiccated by the burning to a point where leaf hoppers and such juice-sucking insects were materially reduced through starvation and desiccation as well as by direct destruction. Leaf hoppers tended to fly out ahead of the

burner, although observations indicated that a large percentage were directly destroyed. The temperature at the time of burning directly affected the primary kill of all active, mobile insects. On warm days, late in the season, coccinellids, syrphids, plant bugs, and other insects were observed to take flight ahead of the burner and even to fly over the flames at safe distances. On cool days this was not possible, and these insects were destroyed unless protected by the alfalfa crowns or by unburned trash. The habits of the species concerned greatly affected this factor, since those species which normally hide beneath trash and plant growth tended to survive. Normal coccinellid eggs were found occasionally attached to trash in protected places in burned-over fields. Insects protected by as much as one fourth inch of soil were generally unharmed. Normal puparia and mature larvae of syrphids were observed late in the season, even in areas where all plant growth and trash had been burned. The season of burning was observed to be a controlling factor in this as well as in other cases. Early in the season the syrphid flies and ladybird beetles, the two most important predators, were usually in the egg or early larval stages, usually in places well exposed to the flames. Later in the season, however, more adults of each existed, and these were often active enough to escape, and at this time there were always a considerable number of syrphid larvae or puparia in protected places. In general, a large percentage of the entire insect population aboveground was destroyed directly or indirectly by burning.

MACHINE PROBLEMS IN BURNING

The machine problems to be met in devising an efficient and economical method of burning a green, low-growing field crop are many and difficult. The time available for burning alfalfa for aphid control is relatively short, and weather and field conditions must be favorable from the standpoint of moisture, humidity, and wind movement. These restrictions necessitate the use of equipment having a fairly rapid burning rate and capable of supplying high burning temperatures with the consumption of relatively low-grade fuels. Moreover, alfalfa as grown in the Antelope Valley is irrigated between borders or low levees, and this calls for a machine that will pass over these obstacles without undue injury to the embankments.

Certain rather specific requirements are thus set up for a successful machine for use in the Antelope Valley. A burning rate of 1 to 1½ acres per hour is desirable. The frame must be flexible, a hood must be provided to confine the hot flame and gases to the low growth that is to be burned, the materials of construction must be heat resistant, and the machine must have a minimum of dead weight. The low-grade fuels to be used must be delivered in proper quantity under relatively low pressures, later to be mixed with air for proper atomization and efficient combustion. The machine must be readily adjustable to meet both field and road conditions, it must be equipped with convenient fuel tanks, and it must be safe and convenient for the operator.

FEATURES OF THE EXPERIMENTAL MACHINE USED IN 1931

The machines used in the 1930 and 1931 experiments were built especially for experimental work and were no doubt more complicated and expensive than commercial machines would be when built to meet well-defined specifications. They are, however, well designed and possess certain essential elements that should be included in a practical field burner. The one used in 1931 (fig. 5, B) more nearly fulfills the necessary requirements for a successful field burner. Its more important features are therefore described in some detail.

A tractor was used to pull the machine and to supply power for the pump and blower which furnished fuel and air to the burners. The machine itself was assembled about a 4-wheeled structural steel frame or chassis. This frame had places for two of the ordinary oil drums in which fuel is purchased, and no transferring of fuel was necessary other than the exchanging of an empty drum for a full one. Quick coupling devices in the fuel lines replaced the usual pipe connections with these drums. The fuel line was also equipped with a quick shut-off valve, a strainer, and a needle valve to regulate the flow.

The oil was delivered to the five burners, which were of commercial make, under a pressure of 30 pounds to the square inch. An air stream from the rotary blower, with a pressure of about $2\frac{1}{2}$ pounds, was directed at right angles to the oil spray, and this atomized the fuel as well as furnished a part of the necessary oxygen for combustion.

The burners were mounted 16 inches apart on centers, with the outside burners 10 inches from the outer edge of the hood. The burners were so attached that each one, or the entire gang together, could be adjusted for elevation through a range of 8 inches, and could be turned from parallel to the ground to an angle of 75° . Field tests indicated that they should at the least be adjustable for use at from 20° to 40° from the horizontal and that 35° would be the most usual setting. Steep angles drive the heat into the crowns but these quickly expend the energy of the flame, making it difficult to control in winds exceeding 15 miles per hour. Steep angles also contribute to smothering and inefficiency of combustion. This was particularly noticeable in wet or green alfalfa or in tall growth.

The flatter angles, however, decreased the effectiveness of the hood length, caused a rapid flow of the burning gases across the under surface of the hood, causing the flame to fail to penetrate the crowns, and caused excessive loss of heat.

The length of hood required depended upon its elevation and the condition of the material to be treated. Hood lengths of from 6 to 9 feet were effective for most conditions of growth where the hood was raised 8 or 12 inches above the ground. The hood must be designed to confine the flame and heat without excessive leakage and at the same time to resist temperatures of approximately $2,000^\circ$ F. In the machine used in 1931 this requirement was met by making the hood cover in sections. The first, or main, section was 7 feet wide and 6 feet long. It was attached to the burner chassis at the rear axle line just back of the five burners. An overhead framework of standard structural iron was used as the support from which the heat-resistant metallic shield was suspended.

Two additional sections of hood, each 3 feet long, were provided, which could be coupled to the rear of the 6-foot hood when additional hood length was needed. These were connected by a short bar pivoted at each end and a rolling support was provided by castor wheels so that the machine was flexible and little injury was caused to irrigation borders. In general, only one of the additional sections was necessary, and in some cases good results were obtained with the 6-foot section alone. It is doubtful if a total length of 12 feet will be found necessary.

The hood was made from sheets of 20-gage chromium-iron alloy, each sheet being 14 inches square. These overlapped one another at all edges to form the hood roof. They were suspended from the framework above by metallic hangers spaced 6 inches apart both ways. This method of construction was necessary to provide a tight cover and to prevent warping of the plates. The side walls and ends of the hood were made flexible also by using similar sheets held in a vertical plane along the respective sides and ends of the hood. The ends were equipped with chain supports made adjustable for fire-draft regulation.

The total weight of the 1931 burner was 2,700 pounds. (Lighter weight is desirable.) The practical forward speeds were about $1\frac{1}{2}$ miles per hour, and the net rate of burning ranged from 1 to $1\frac{1}{2}$ acres per hour. Fuel consumption must be varied to meet operating conditions, but difficulty was experienced in keeping the burners lighted when the fuel rate was less than 30 gallons per acre. A commercially built machine should be designed to allow fuel rates of twice this quantity, although double burning at low rates is much more effective than a single burning at a high rate.

Mechanical atomization was effective with the higher-grade fuels, but air atomization was more effective with the low-grade oils and was equally as efficient with the better grades. The latter is also safer owing to the lower fuel pressures possible. The quick shut-off valve installed in the fuel line and easily operated from the driver's seat was installed as a safety factor. Joints in the fuel line should be set up tightly with an oil-proof cement to prevent leaks. The machines used in the test work had the joints cemented with a paste made from glycerin, litharge, and lampblack, the latter being added to make it harden more quickly. This cement gave very satisfactory results.

SUMMARY OF DESIRABLE FEATURES

Some of the characteristics found to be of particular advantage in the construction of a field burner are the following:

The burner should be drawn by a tractor with power take-off.

The machine should be supported on a 4-wheel chassis with fairly short turning radius and with the rear axle placed at the front end of the hood in line with the nozzles of the burner gang.

The dead weight of the machine should be kept as low as possible.

Arrangements for a rapid means of refueling are essential. The use of fuel from the original container is feasible when quick detachable pipe connections are provided.

Burners should be spaced to provide complete coverage. One row of burners is preferable.

The burner nozzles should be at least 7 feet to the rear of the tractor seat.

Fuel nozzles should be adjustable for height and angle of discharge. Fixed nozzles should be 10 inches above the ground surface and inclined 35° from the horizontal for air atomization and 40° for mechanical atomization.

Air and fuel pumps should be driven from the tractor power take-off.

The proper air-fuel ratio for efficient combustion must be maintained. This requires an auxiliary air supply with proper controls for volume and pressure.

Fuel pumps should be equipped with by-passes to maintain uniform fuel supply at the nozzle.

Fuel lines must be equipped with safety relief valves, quick shut-off valves, and fuel strainers.

The air lines must be equipped with safety relief valves and with a surge chamber to absorb air pulsations from the compressor.

Mechanical or air atomization of fuel may be used successfully. The latter is considered safer and more efficient with low-grade fuels. Diesel oils (27° B. and higher grades) may be used successfully with air atomization except where temperatures are below 30° F.

Hoods must be constructed of heat-resisting materials with flexible roof and side walls and with flexible, adjustable ends for draft control.

The hood of the machine should be at least 6 feet long and should have approximately 12 inches of clearance.

QUALITY AND QUANTITY OF FUELS FOR BURNING

The fuels used in the various field experiments ranged from Diesel oils of 27° B. and higher grades to 39° B. distillate. The cost of fuel ranged from 5 to 9 cents per gallon, depending upon grade of fuel and availability. In general, Diesel oils were satisfactory, and these, when purchased in car-lot quantities, can be secured at prices less than the lowest unit price quoted above.

The quantity of fuel used was also variable, ranging from 25 to 70 gallons per acre. With the air-atomization type of burner, applications of 30 to 40 gallons per acre were satisfactory for single burning. Somewhat higher rates were used with mechanical atomization. Where double burning was desirable, applications of 30 gallons per acre for each burning were necessary. The second burning was always done at the same rate as the first burning. In fact, with burning rates of less than 25 gallons per acre trouble was experienced in keeping the burners lighted. This rate was equivalent to approximately 5 gallons of fuel per burner per hour.

COST OF BURNING

The cost of burning with the experimental machines in 1930 and 1931 is based on an initial machine cost of \$1,400 (exclusive of tractor); depreciation 15 percent; interest 7 percent (based on average investment); tractor and operator cost \$1.50 per hour; rate of burning, 10 acres in 10 hours; and an annual burning season of 15 days. The actual period when burning may be done lasts approximately 21 days, that is, from March 12 to April 1, inclusive; but

during some of this time wind movement and moisture conditions are unfavorable for field work. For these reasons the 15-day period is believed to be the proper basis for the estimate. In this time 150 acres may be burned over once, or 75 acres twice. Though various grades of oil were tried out experimentally, 27° B. Diesel oil, costing 5 cents per gallon, is used in the estimates, since satisfactory results were obtained with this grade of fuel.

SINGLE BURNING WITH 1930 OR 1931 BURNER

	<i>Cost per acre</i>
Fuel: 27° B. Diesel oil, 35 gallons per acre at 5 cents per gallon-----	\$1.75
Power and labor: Tractor with driver, 10 acres per day of 10 hours at \$1.50 per hour-----	1.50
Depreciation: 15 percent of original cost and based on 150 acres per season-----	1.40
Repairs: Based on field experience-----	.10
Interest on average investment of one half initial cost at 7 percent and based on 150 acres per season-----	.33
Total cost per acre-----	5.08

DOUBLE BURNING WITH 1930 OR 1931 BURNER

Fuel: 27° B. Diesel oil, 60 gallons at 5 cents-----	\$3.00
Power and labor: Tractor with driver, 5 acres in 10 hours at \$1.50 per hour-----	3.00
Depreciation: 15 percent distributed to 75 acres-----	2.80
Repairs-----	.20
Interest at 7 percent on average investment distributed to 75 acres-----	.66
Total cost per acre-----	9.66

The foregoing estimates are based on the cost of an experimental machine. It should be possible to construct a commercial type of machine to meet the practical requirements for satisfactory burning for approximately \$1,000. This would reduce fixed charges (interest and depreciation) to \$1.23 per acre for single burning, which would make the total cost \$4.58 per acre, of which approximately 73 percent would be due to operating expenses and 27 percent to fixed charges.

The cost of burning with the Canadian field burner is somewhat less per acre, but the effectiveness of burning is much below that of the Department of Agriculture type of burner. An estimate of the cost with this type of burner, based on a cost of \$300 for the machine alone, is as follows:

SINGLE BURNING WITH CANADIAN BURNER

	<i>Cost per acre</i>
Fuel: 38° B. distillate, 16 gallons per acre, at 9 cents-----	\$1.44
Man and team: 50 cents per hour; rate of work, 1 acre per hour-----	.50
Interest on average investment of \$150 at 7 percent, distributed to 150 acres-----	.07
Repairs, per acre-----	.10
Depreciation at 20 percent for 150 acres-----	.40
Total cost per acre-----	2.51

DOUBLE BURNING WITH CANADIAN BURNER

Total cost per acre-----	\$5.02
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Since double burning with the Canadian type of machine is less effective than single burning with a machine of the Department of

Agriculture type, the latter is really more economical even though a much higher initial investment is necessary.

IMPORTANCE OF CLIPPING

Although burning by the fuel alone can be made effective in itself, it must be remembered that dry litter tends to augment the flame and promote combustion. Accordingly, effective burning can be facilitated in some fields if the top growth be previously clipped to provide this litter and to remove heavy growth which would otherwise protect the crown areas. If the clipped material should pack closely to the ground or into the crowns, owing to rain or other causes, it should be stirred or loosened with a spike-tooth harrow to form a dry, fluffy mass before being burned with the machine.

EFFECT OF BURNING ON ALFALFA

Burning has a pronounced effect on the alfalfa itself. The new growth is much more leafy, and the stems are more succulent during the early stages of growth. Examinations failed to show any detrimental effects upon vigorous stands. In one series of plats known to be seriously affected by bacterial wilt some reduction in stand resulted, but no more than in unburned checks similarly affected by the wilt. One plat burned exceptionally late in the season developed a somewhat coarser growth than unburned checks in the same area. Plats burned before the time when vigorous growth occurred, however, produced a finer, denser, as well as a more even type of growth than areas not burned. The increase in vigor of burned stands may be accounted for as follows: (1) A better chance to grow, due to the reduction of aphids and of other insects; (2) better exposure of the ground to the sun, due to removal of considerable of the dry material; (3) a possibly greater absorption of heat by the soil, due to the dark color of the burned-over area; and (4) reduction of the weed growth which was entering into competition with the alfalfa.

The behavior of the alfalfa in some plats is shown in figures 9, 10, and 11, which show average heights in test plats and in corresponding unburned areas. The early burned plat (fig. 9) in 1931 had a poorer stand of alfalfa than the check plat. The burned area in this case was very severely reinfested, and the untreated part of the field had a considerable portion of the aphid population drained from it. Consequently the plants in the unburned part of the field made a good growth. The other figures indicate that the test plats consistently made more growth than their check areas. Table 3 shows comparative yields from plats burned on different dates in 1930 and 1931. In view of variations in temperature and humidity for the 2 years, it could hardly be expected that results would be identical. However, in general, good control of aphids was not obtained from plats burned early in March. Burning done in April was of little value other than to improve the quality of hay, since natural recovery begins about that season of the year. There appears to be a tendency for late burnings to produce a coarse-stemmed crop.

Burning cannot be expected to increase the vigor of diseased stands or to take the place of reseeding or rotating with other crops when these measures are necessary.

COMPARISON OF YIELDS FROM BURNED AND UNBURNED PLATS

Hay samples taken from two sets of plats of 0.001 acre each in 1930 gave the weights shown in table 3 on the basis of cured hay.

TABLE 3.—*Alfalfa yields from burned and unburned plats in 1930 and 1931*

Date of burning	Date hay sample was taken	Yield of dry hay per acre	Date of burning	Date hay sample was taken	Yield of dry hay per acre
1930			1931		
Unburned (check).....	May 13	<i>Pounds</i> 1,375	Feb. 24.....	May 4	2,839
Do.....	do	2,375	Mar. 5.....	do	3,222
Mar. 28.....	do	4,600	Mar. 19.....	do	3,473
Apr. 1 to 6.....	May 15	7,392	Mar. 24.....	do	3,364
Unburned (check).....	do	5,313	Check (unburned).....	do	2,801

The samples from the experiment of April 1 to 6 and its check no doubt show exaggerated yields for some reason connected with sample taking, but it is thought that the weight ratios are essentially correct.

The five square-yard samples from each of four burned plats and one untreated area, taken in 1931, indicated the yields of cured hay per acre also shown in table 3.

Aphids left the check and went into adjacent burned plats, thereby aiding growth on the check and reducing it on the treated areas.

In the cases observed the quality of hay on plats burned at the proper time was consistently superior to that from those left untreated. This has been shown as well in whole fields where burning has been practiced. Frequently, owing to aphid damage and the presence of weeds the first crop of hay from unburned areas is unsalable or can be used only as fertilizer hay, whereas when these fields have been burned over the hay has commanded premium prices.

SUMMARY

The pea aphid causes heavy losses to alfalfa in southern California. If the aphids have become very numerous the first crop can be saved, so far as known, only by burning over the fields within a very restricted period, from March 12 to April 1 being usually the time within which the operation is profitable. Earlier burning permitted serious reinfestation.

The first year's experiments were made with a burner fastened in front of a tractor. This type was found unsatisfactory, and the smoke and flame from the burning material caused great discomfort to the operator as the tractor passed over it.

For the experiments of 1930 a burner was constructed which was pulled by a tractor, and with the experience gained by its use a much improved machine of somewhat similar type was designed and built by the United States Department of Agriculture for use in the 1931 work. A detailed description of this burner is given, and the results of the experiments of 1930 and 1931 are discussed.

It was found that burning could be made more effective by previously cutting the alfalfa and allowing the cut material to dry on the field. The new growth which appeared on the alfalfa stems

was more succulent than that on the unburned tracts. The alfalfa on the burned tracts usually attained a greater height than that unburned before the time of the first cutting and was generally free of weeds, whereas the hay from unburned tracts was frequently unmarketable. For satisfactory control of aphids and weeds the burning should be done each spring. The burned fields should be irrigated as soon as the new growth starts.

Reinfestation results from the few survivors, augmented by winged migrants attracted by the more succulent growth, and these are favored by the fact that many natural enemies have been destroyed. Too early burning favors reinfestation in each of these factors. After the last of March natural climatic conditions largely prevent a serious reinfestation.

On warm days a considerable number of the insect enemies of the aphids fly away from the approaching burner. On cool days and earlier in the season they are likely to be killed.

The fuels used for burning ranged from Diesel oils of 27° B. to distillates of 39° B., the oils costing from 5 to 9 cents per gallon. The quantities used ranged from 30 to 40 gallons per acre for single burnings, and 30 gallons was required per acre for each operation in double burning. With the improved burner a single burning cost about \$5.08 per acre, and a double burning about \$9.66, including all expense factors, which are given in detail.

Comparison of yields from burned and unburned areas showed a substantial increase in yield in the first cutting, the one principally benefited.